Fermi National Accelerator Laboratory

Ripple Filter for the 10,000A Superconducting Magnet Test Stand at the Magnet Test Facility

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RIPPLE FILTER FOR THE 10,000A SUPERCONDUCTING

MAGNET TEST STAND AT THE MAGNET TEST FACILITY

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1. INTRODUCTION

The new 10,000A dumpswitch [1] and dumpresistor [2] system at MTF required a 720Hz filter to eliminate power supply ripple from the load. The new filter, shown in Figure 1, had two requirements:

1. Less then 1/2 A_{p-p} ripple current with a load current of 10,000A.

2. No or minimal overshoot when the current reaches flattop after it is ramped to 10,000A.

MTF magnets are ramped to their final current values at different ramp rates depending on the inductance and type of the magnet under test. The filter design was done with the help of PSPICE simulations. Most of the simulations that will be shown in this write-up were done using a 50mH magnet and a ramprate of 200A/s. In order to study this filter with SPICE, two different simulations had to be done. Due to the relatively high frequency of the ripple when compared with the ramping times, if the ripple current was studied together with the overshoot, the simulations would have taken a very long time to run. Therefore the voltage ripple and the current overshoot were studied separately.
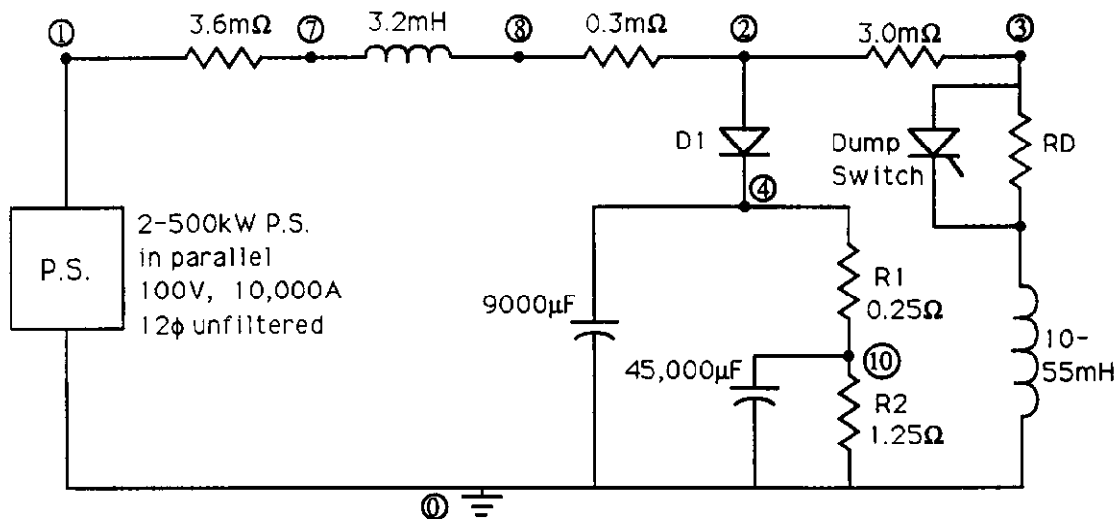
Figure 1: Filter configuration

2. VOLTAGE RIPPLE

Figure 2 shows the output ripple voltage that closely resembles the maximum ripple components of the 12φ unfiltered 500kW power supplies. It also shows the voltage across the magnet. As it can be seen from this plot, the voltage across the magnet shows no ripple in it. Closer examination reveals that the magnet voltage ripple is only ~50mV, which indicates that the current ripple will remain under 1/2A_{p-p}.
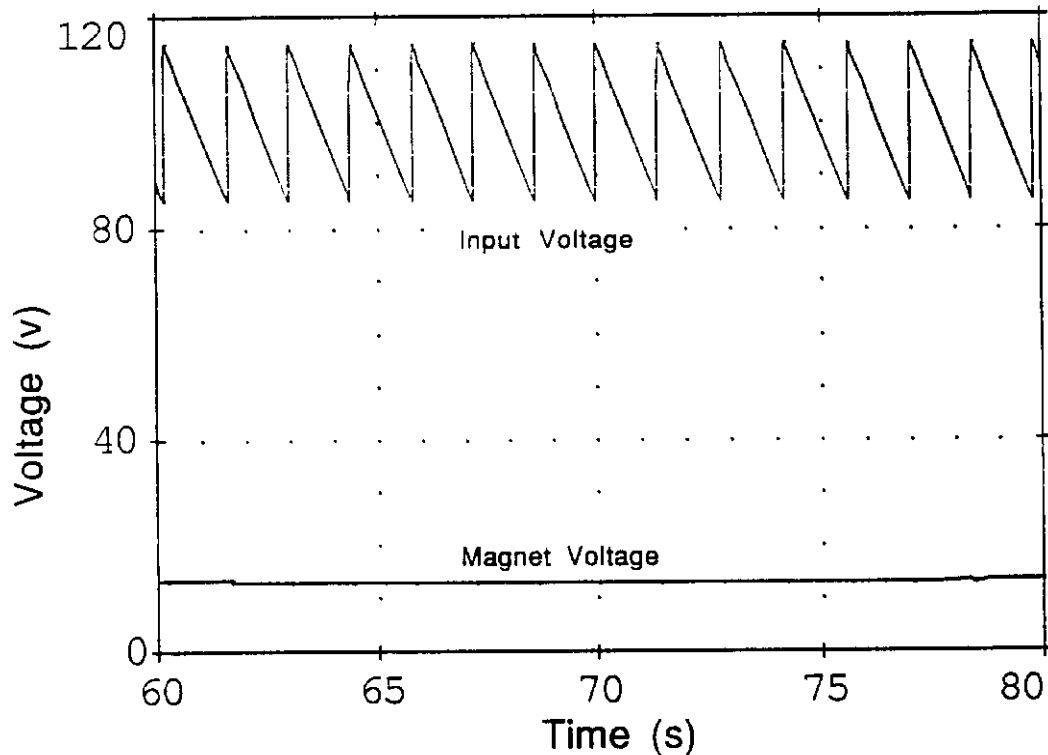
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Figure 2: Voltage in and out of the filter

3.   CURRENT OVERSHOOT

The current out of a power supply as it is ramped to 10,000A at 200A/s is shown in Figure 3a. The current through the load due to this input looks very similar to the input, but if the area where the ramp reaches 10,000A is enlarged as it is shown in Figure 3b, a ~3.5A overshoot in the load current can be seen. This overshoot is due to a sharp reduction in power supply voltage as dI/dt goes to zero. Although this overshoot is not too much, this value is the maximum theoretical overshoot that will be present in the current. The overshoot in the actual circuit will be smaller due to two reasons that could not be included in the SPICE models. One of these reasons is that actual power supplies are regulated from the load current, not from the power supply current as the SPICE model indicated. Since the power supply is regulated from the load current some of the overshoot caused by the filter would be compensated for by the regulator. The other reason why the actual overshoot would be smaller then indicated here, is that MTF magnets are ramped with the use of a special ramp module, which parabolically smooths rough edges in the voltage waveform. As changes in the power supply voltage become smoother, the current overshoot is also reduced. Several other filter configurations were tried, but it was found that in cases where the overshoot was further reduced, the ripple filtering ability decreased. The resistance value of damping resistors R1 and R2 (Fig. 1) affect the overshoot. Smaller values reduce overshoot, but increase losses. Therefore one consideration in choosing R1 and R2 was to keep the losses low.
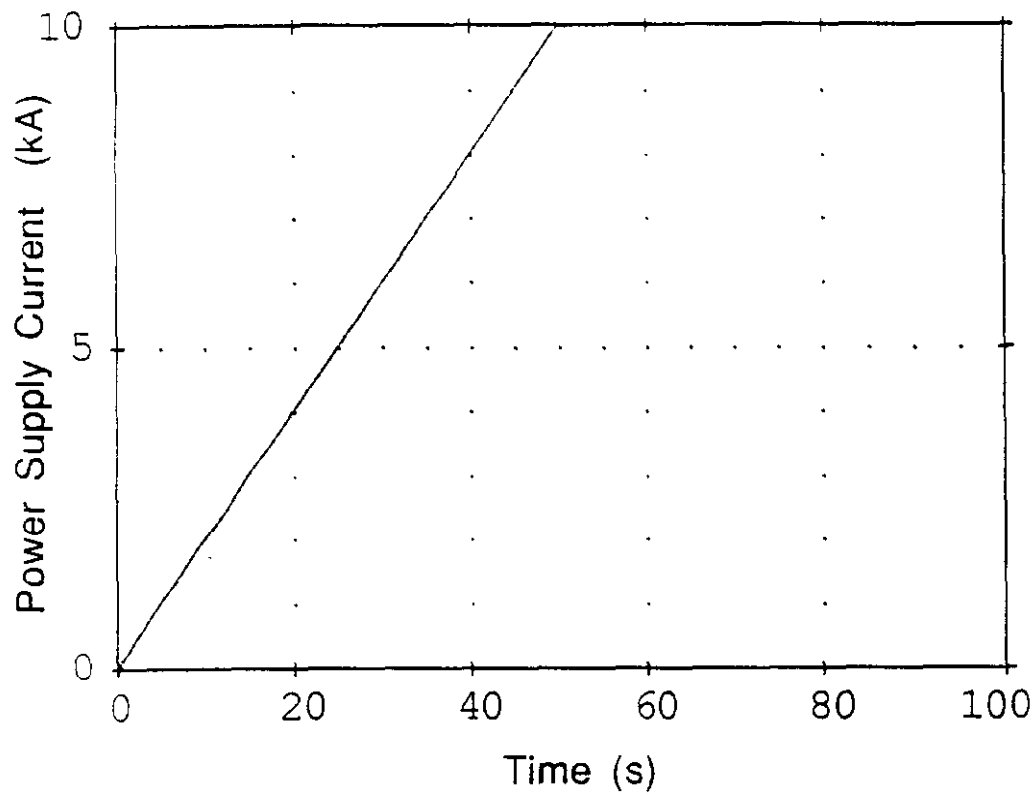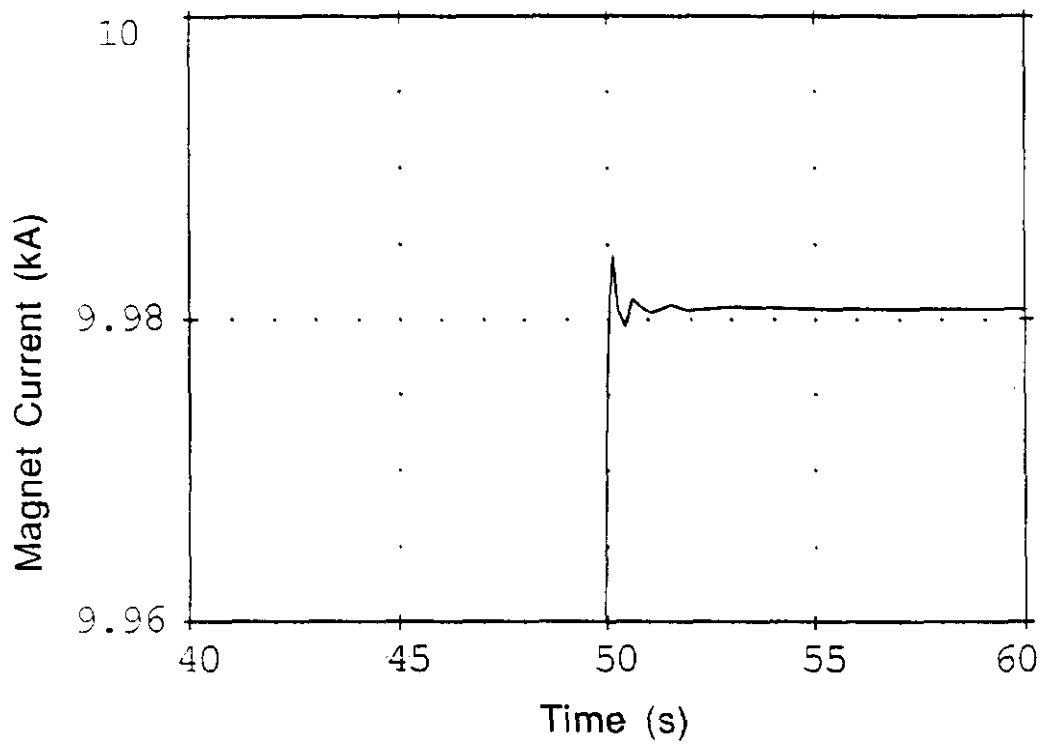
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Figure 3a: Power supply output current

Figure 3b: Magnet current overshoot

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4.   FILTER CROWBAR

As the complete dumpswitch circuit with the filter included was studied it was noticed that whenever there is a short for a load, which is often done when the system is tested, at the time the dumpresistor is put into the circuit, the voltage across the filter caps rises sharply to a very high value (close to 1000V). This can be easily seen by looking at Figure 4. If the circuit is in steady state with 10,000A through it, and the 100mΩ dump resistor is suddenly put into the circuit, for a short time this resistor will have almost all of the 10,000A going through it, which would develop close to 1000V across the capacitors. Since the filter capacitors are not rated for such a high voltage, a crowbar circuit was designed to short the capacitors in case of this sudden rise of voltage. PSPICE was again used to gain better understanding of how quickly the crowbar circuit had to be inserted across the capacitors. The surge voltage rating of the electrolytic filter capacitor bank is 300VDC. To have a safety factor of 100V, the trip value of the crowbar is set at 200VDC. To know how long it takes the capacitor voltage to reach 200V, the dump circuit, as shown in Figure 4, was modeled on PSPICE. In this figure the SCR represents the dumpswitch. A dump signal is initiated when the power supply voltage reaches zero. The plot of the input voltage and the voltage across the filter is shown in Figure 5. Looking at the plot, it can be seen, that the actual capacitor voltage reaches ~200V in ~200μs after a dump signal is initiated. This means that a crowbar circuit had to be designed that would short the capacitors in ~200μs. The final crowbar circuit consists of a frequency compensated voltage divider and a diac which fires a crowbar SCR whenever the voltage rises above 200V. The crowbar circuit along with the filter circuit is shown on drawing #ATV012291MTF. A large crowbar SCR is chosen to withstand a possible unscheduled (failure) turn on during running conditions.
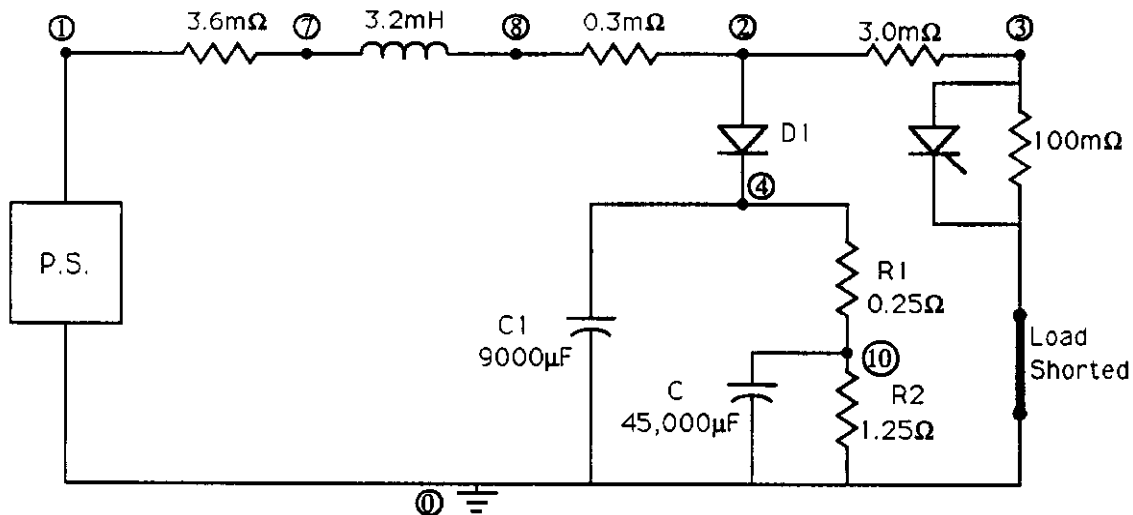

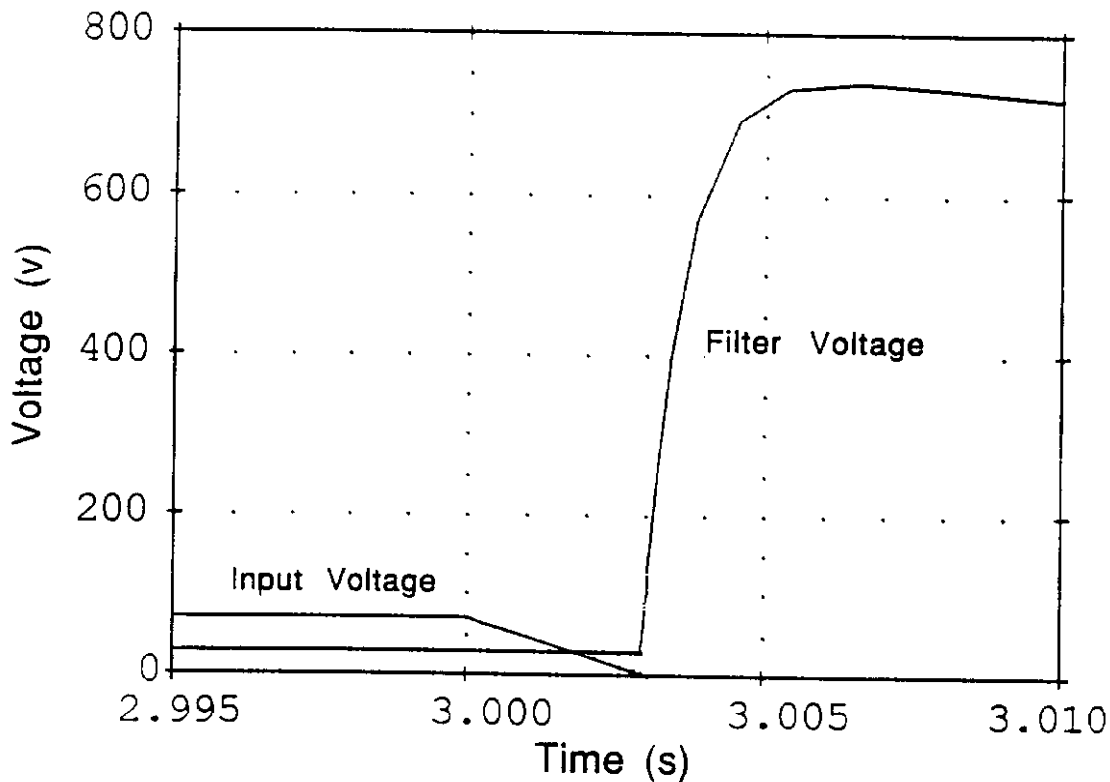Figure 4: Circuit for testing the dump

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Figure 5: Filter voltage rise due to a dump with the load shorted

5. CHOOSING THE COMPONENTS

Once the design of the filter and the crowbar were done, the capacitors and the resistor had to be purchased. To study the maximum and steady state voltages and currents in the circuit, SPICE simulations were done. These simulations were done to determine the ratings of the individual components. To study the maximum voltages and currents during steady state, a simulation was done with no load attached to the system. The power supply was outputting 100V with a $40V_{0-p}$ ripple superimposed on it. The results of this simulation are given in Table 1.

Table 1: Maximum steady state values

Component	Value
V(C1)	120V
I(C1)	$2.5A_{p-p}$
V(C)	100V
I(C)	$<1A_{p-p}$
I(D1)	80A
P(R2)	8kW
P(R1)	1.5kW

To study the transient response of the filter, a 100V step function was the voltage input. The maximum currents and power dissipated in the components, due to the step voltage, are given in Table 2.

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Table 2: Maximum values due to step input

Component	Value
I(D1)	280A
I(C)	190A
I(C1)	60A
P(R2)	9kW
P(R1)	13kW

6.   CHOOSING THE RESISTOR

From Table 1, it can be seen that in the worst case situation with no load, the resistors have to dissipate a substantial amount of power. From Table 1, we get that the steady state power dissipated is $P(R_1) + P(R_2)$ which is 9.5kW. To purchase resistors, that could handle this power, would have been quite expensive. Also packaging them would have taken a lot of space. Therefore it was decided to use stainless steel tubing to make a watercooled resistor. This has cut down the cost and the size of the resistor. The tubing that was chosen was 1/4 x 22 SS. In order to calculate the length of the tubing required, the resistance/ft (R/ft) of this tubing had to be calculated. The R/ft can be calculated using the fact that a $1in^2$ SS bar has R/ft=.34 $x10^{-3}\Omega$/ft and it has a weight/ft=3.4lbs/ft. The 1/4 x 22 SS tubing has a weight of .0664lbs/ft. Using this information, the R/ft of the SS tubing is calculated.

$$\frac{R}{ft} = \frac{3.4}{.0664} \times .34 \times 10^{-3} = 17.4 \text{ m}\Omega/\text{ft}$$

we need 1.5Ω

$$1 = \frac{1500m\Omega}{17.4m\Omega/\text{ft}} = 86.16 \text{ ft}$$

Therefore the length of the tubing needed is 86.16ft.

1 GPM of water flow is needed to take away 10kW of heat generated in the resistors with a water temperature rise of 38° C. The finished resistor was tested for the amount of water that can flow through it and it was found that the flowrate at a $\Delta P=45$ PSI was 0.83 GPM. Therefore at a ΔP of 100 PSI, which is the water pressure available at MTF, a flow-rate of 1GPM through the resistor should pose no problem. But just in case there is ever a loss of water flow in the resistor, the resistor is also protected by two 120^oC klixons, which will trip off the power supply in case the resistor was overheating.

A drawing of the resistor with all of its actual specifications and ratings is given on the drawing# ATV031491MTF.

7.   CAPACITORS

Table 1 was used to choose the capacitors also. From Table 1 it can be seen that the maximum steady state voltage across the caps is about 120V. For a safety factor of 2, 250 WVDC

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capacitors were chosen. The ripple current through these capacitors, even for the worst case ripple, is very small, therefore just about any capacitor can handle the ripple current. the maximum possible current values in Table 2 were used to choose proper values for the fuses which are used for circuit protection in case of capacitor failure.

8. ACKNOWLEDGEMENTS

Age T. Visser designed the resistors and the filter crowbar. He was also very helpful with his suggestions regarding the design of the filter. I am grateful for all his help.
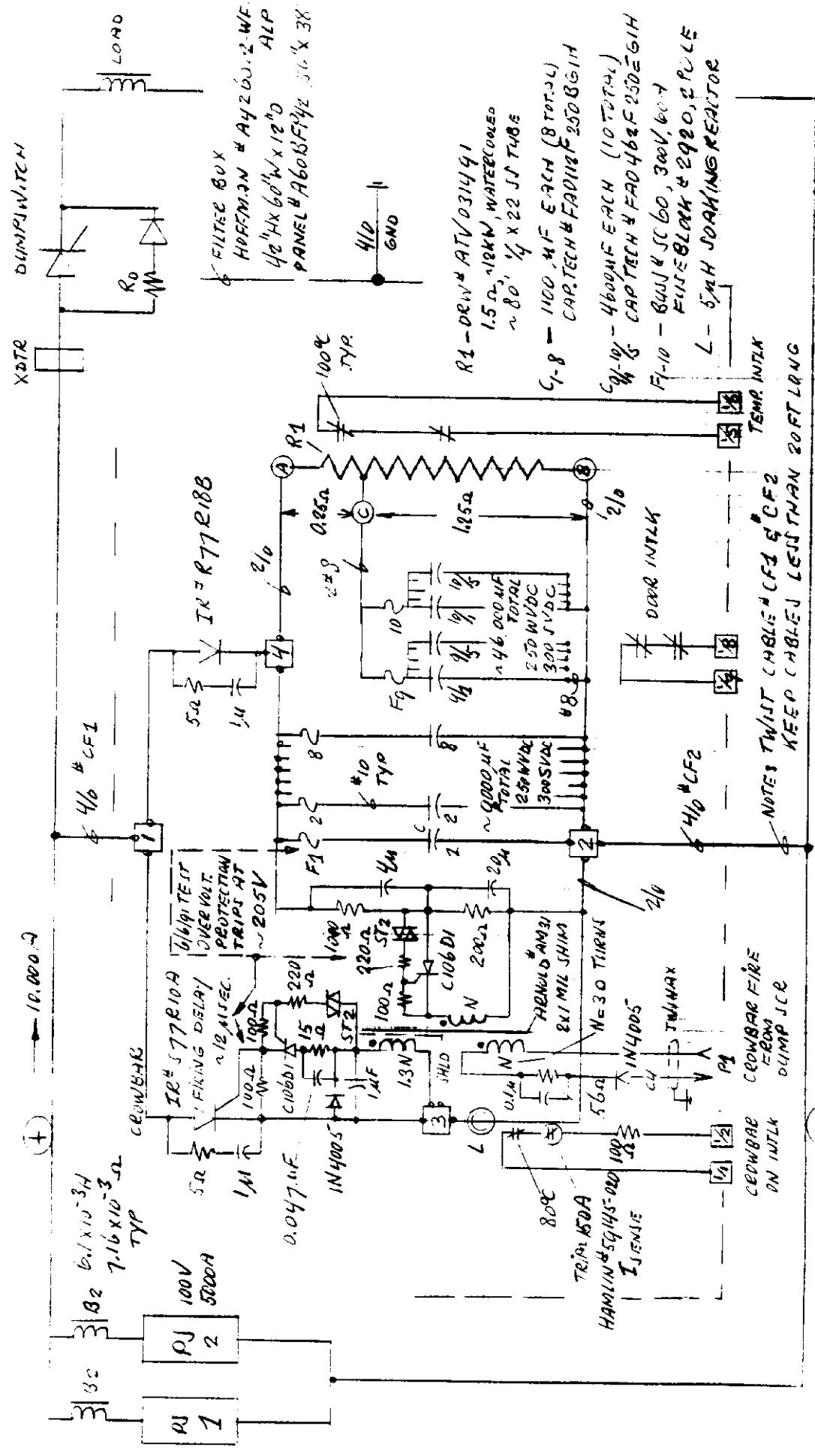
Walt Jaskierny built and tested the filter. His contribution is appreciated.

9. REFERENCES

[1]   TM# 1161 Cat.# 2080.000, A. T. Visser March '90, Design note of a 10,000A, 2MJoules Dump Resistor for the Magnet Test Facility.

[2]   TM# 1692 Cat.# 2080.000, A. T. Visser October '90, Design note of a 10,000A, 1000VDC Solid State Dump Switch for the Magnet test Facility.

FERMILAB ENGINEERING NOTE

SECTION E60-8J PROJECT MTF

SUBJECT: MTF 10,000A/1000 DUMP TEST STAND, P.S. RIPPLE FILTER AND OVERVOLTAGE PROTECTION

NAME AVINE-Z/DRENNAN DATE 1/24/91 REVISION DATE 3/26/91

DRW# ATV-01229/ MTF-
REV 6/10/91 AS BUILT

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL/CATEGORY	PAGE
EHD	MTC		

SUBJECT: MTF 10,000 Ω/1000 V OHMIC SWITCH
1.5 Ω RIPPLE FILTER DAMPING RESISTOR R₁

NAME	A.T. Visser
DATE	3/14/91
REVISION DATE	

WATER COOLED

CUT 20 LENGTHS OF 48" EACH - ¼ x .022 SS TUB.

INSERT TROUGH 4 SUPPORT BLOCKS
BRAZE 180° RETURNS, POWER FEEDS, BRAZE.
INSTALL TAP C 250 mΩ (∿ 13.6 FT FROM A)
$A-C = 250\ m\Omega$
$A-B = 1.5\ \Omega$

SIL. RUBBER AFTER ASSEMBLY FOR SPACING

180° RETURN
#180 FF4

¼ x .022 SS TUBE

3 PCS ¾ BC
¼ THICK CU
POWER FLAG
FOR ⅜ LUG
#8 INDEX 4 PLS ⅖

SPACER
SUPPORT BLOCK

180° RETURN BEND HIGH
180° RETURN BEND LOW
¼ x .022 GA
S.S. TUBE

MAKE 2 SPACER BLOCKS 3¼ x 1, AND 2 PCS 3¾ x 5¾
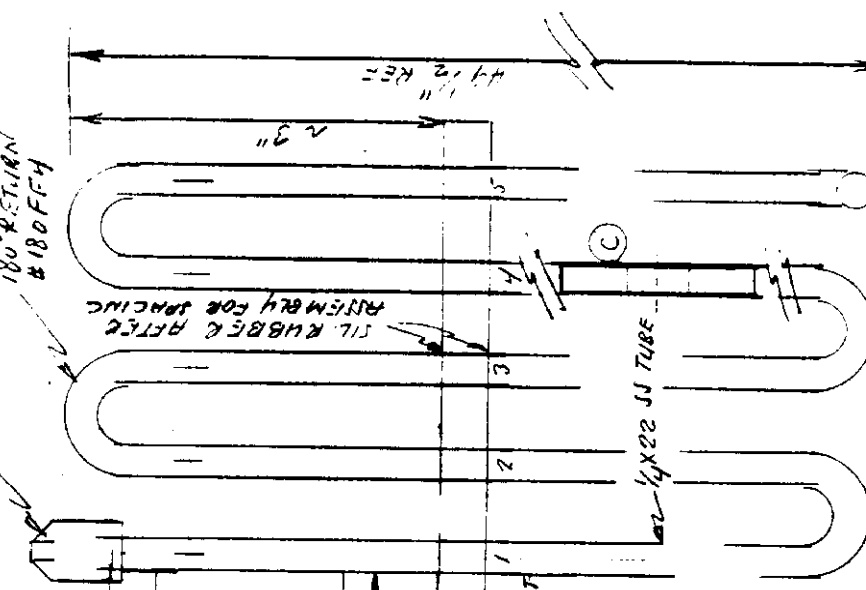¼ THICK, TEFLON
EACH WITH 20 - 9/32 HOLES AT ¾ CENTERS

NOTES:

¼ x .022 GA SS TUBE MEASURED $R = 17.9 \times 10^{-3}\ \Omega/ft$ 20°C (WF)

RESISTOR RATINGS: 1.5 Ω NOM. 12 KW, WATERCOOLED
  $A-C = 250\ m\Omega$, $A-B = 1.455\ \Omega$ AT 20°C
  FLOW = 0.83 GPM AT ΔP = 46 PSI
  PRESSURE 400 PSI

4/9/91 TESTED :

2 PCS
HOSE FITTING MODIFIED
⅜ MALE FLARE TO ¼" TUBS.

180° RETURN
#180 FF4